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Stevens Institute of Technology
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An Experimental and Theoretical Investigation
of Turbulence Instabilities at Plasma-Magnetic
Field Interfaces

Semi-Annual Report

April 1965

Winston H. Bostick

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Office of Research Grants and Contracts
Code SC, National Aeronautics and Space Admin.
1520 H Street, N. W.
Washington 25, D. C.

A. Turbulence from Eddies in the Plasma Coaxial Accelerator

The Semi-Annual Report of October 1964 gave a fairly detailed account of the probe measurements which delineate the plasma eddy pattern in the coaxial plasma accelerator. This work also has now appeared in the Physics of Fluids 8, 745 (1965). Elliot Farber, graduate assistant associated with this work at Stevens, has now essentially completed his Ph.D. thesis on this subject. His thesis will be published as a laboratory report.

Image converter photographs have been taken of the operation of a plasma coaxial accelerator, where the outer conductor is made of a screen, simultaneously with probe measurements. The photograph and probe measurements show that the main current carrying sheath is planar on the front and bullet-shaped on the rear, and that the luminosity in the rear is considerably greater than at the front.

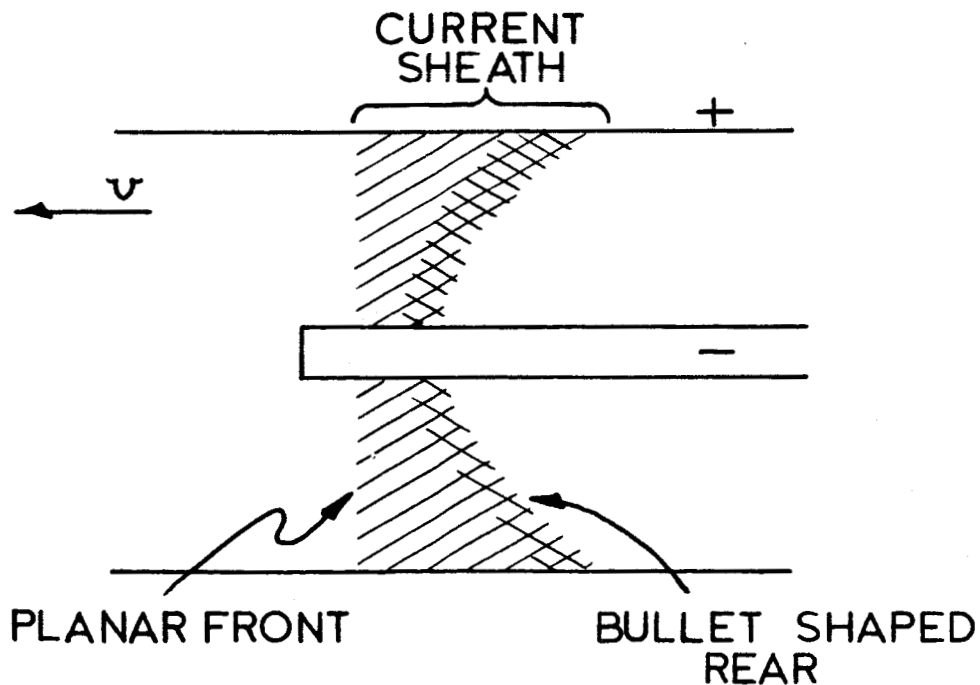


Fig. 1

Image converter photographs have also been taken of the plasma coaxial accelerator (with the wire screen outer conductor) when the current sheath has left the end of the inner conductor, (figure 2).

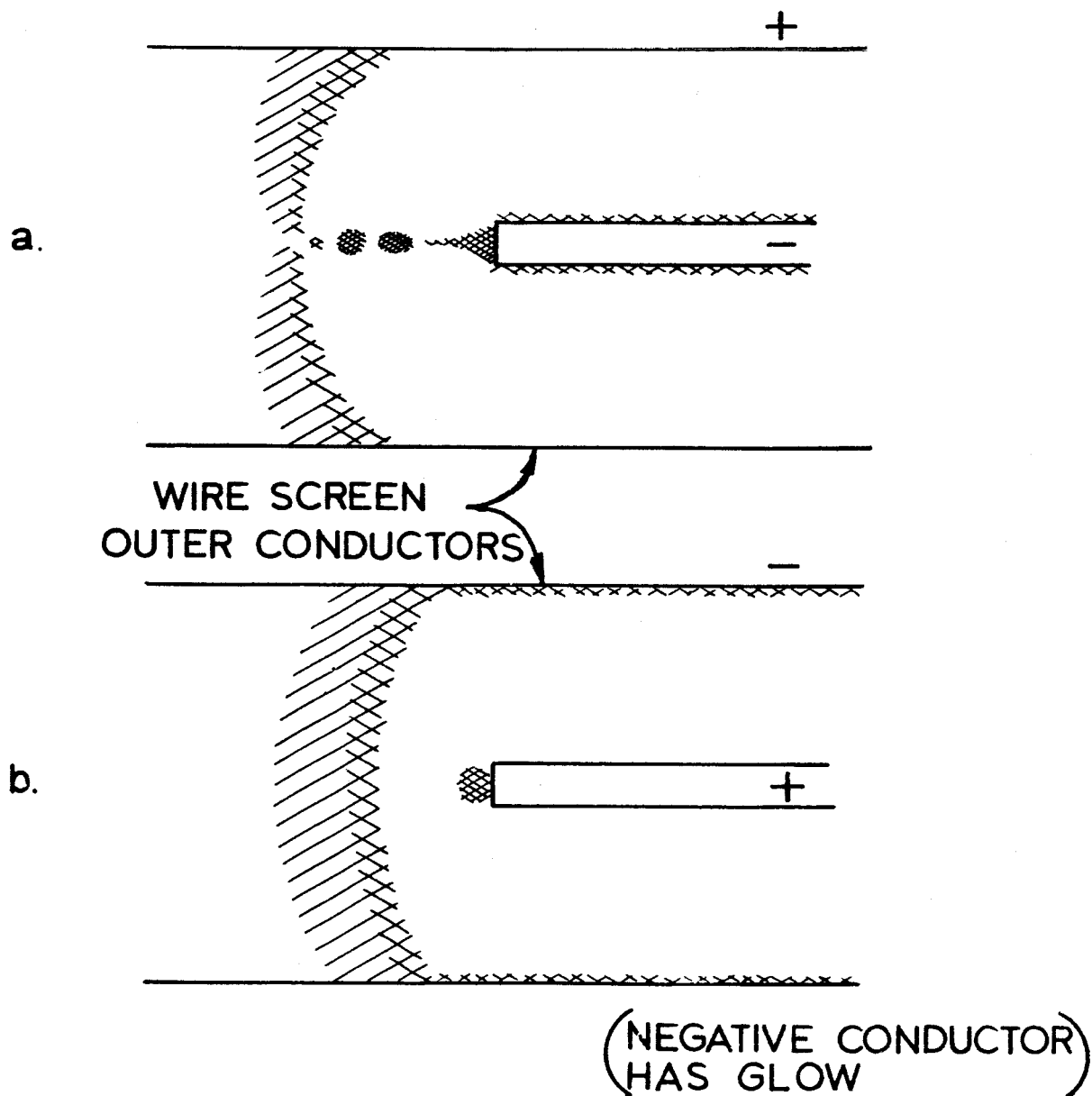


Fig. 2

When the inner conductor is negative the plasma can be observed to leave a luminous cone at the end of the center conductor and two or three blobs of plasma beyond. Then the center conductor is positive, a bright luminous ball is observed at the end surface of the copper inner conductor, and a "luminous plasma-coating" is observed to remain on the anode, even when the current front has passed several centimeters beyond the end of the center conductor. Probe measurements are now in progress to explore this region beyond the center conductor.

Probe measurements are also proceeding on the parallel-plate plasma accelerator where image converter photographs in hydrogen show clearly the presence of plasma eddies, (figure 3).

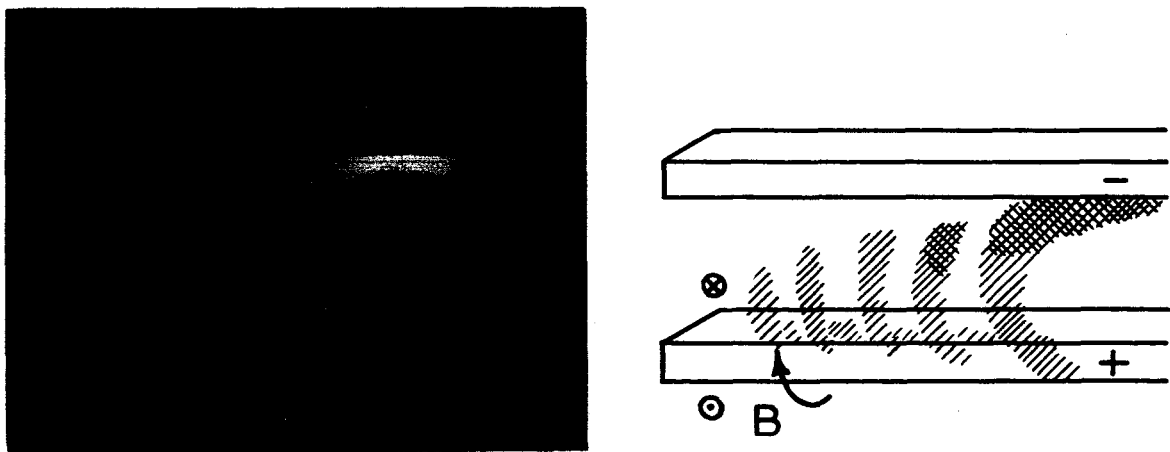


Fig. 3

B. Turbulence in Plasma Flow over a Dipole

Some of the experimental results of plasma flow over a magnetic dipole are summarized, "Flow of Plasma Around a Magnetic Dipole", which has been accepted for publication in the Physics of Fluids. Additional results are reported in the accompanying report, "On the Intrusion of Plasma Into a Model Magnetosphere", W. H. Bostick, H. Byfield and A. Jermakian. A Master's thesis has resulted in the report ECOM-2587, "A Study of Ionospheric Irregularities and Their Relation to Laboratory-Produced Plasma Vortices", W. H. Bostick and A. Papayanou.

A two-wire plasma button gun has been fired in the dipole field (i.e. near the loop coil) and also into a coaxial field. In both cases the columnar vortices lined up along the magnetic field are observed. In the case of the coaxial field, the plasma trajectory as photographed, is deflected away from the region of larger field, as shown in figure 4.

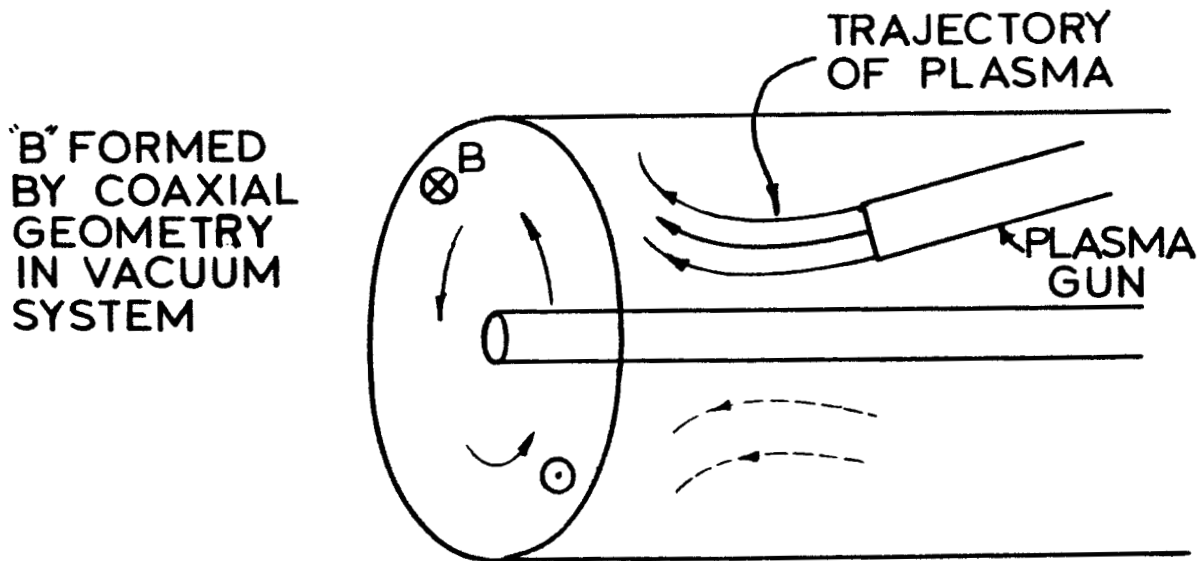


Fig. 4

C. Production of Individual Plasma Eddies by Means of a Two Wire Button Plasma Gun Fired into a Homogeneous Magnetic Field

Measurements with a battery of double probes have detected clusters of rolling eddies or vortices traveling across a homogeneous magnetic field into which has been fired a two-wire button plasma gun, (figure 5).

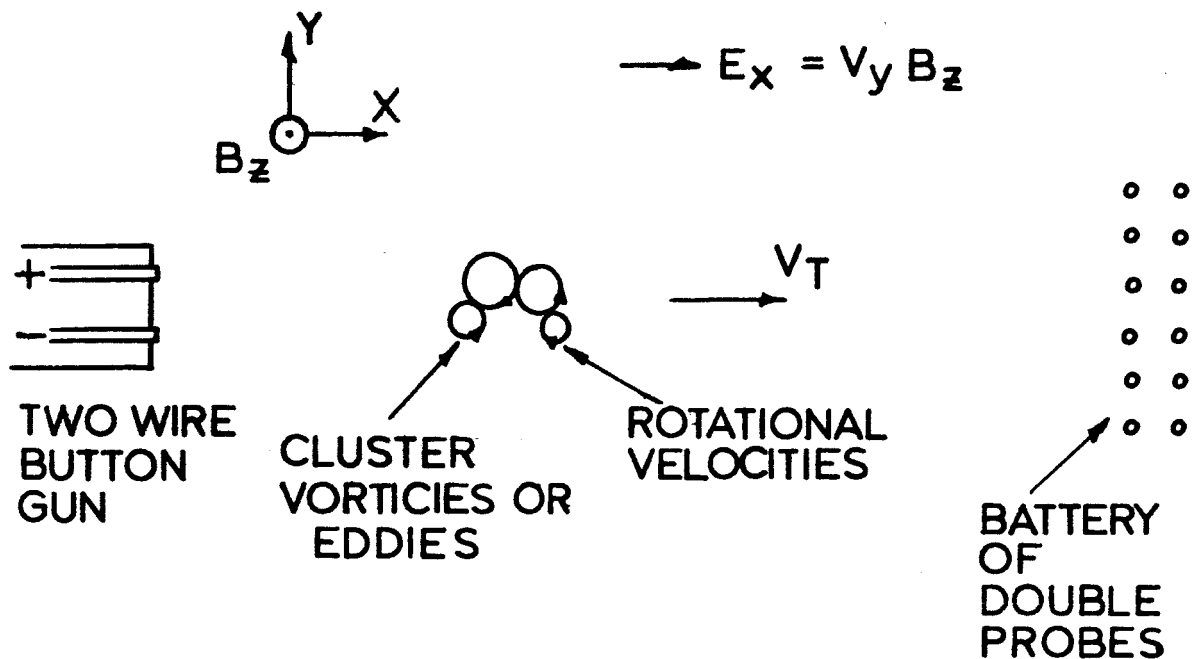


Fig. 5

Preprint, "On the Intrusion of Plasma Into a Model Magnetosphere" follows.

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ON THE INTRUSION OF PLASMA INTO A MODEL MAGNETOSPHERE

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Various laboratories have made models of the Solar Wind interaction with a magnetic dipole¹⁻⁷, and there is general agreement on the gross details of this interaction, e.g., on the shape of the upstream magnetospheric boundary, on the factors determining standoff distance, etc. Most experiments also find that there is intrusion of plasma into the magnetosphere (shown by photographs of luminosity within the magnetosphere, deposits on the terella surface, and probe measurements) so that plasma may be detected inside the magnetosphere on the upstream side of the terella, and also in a tail downstream. Intrusion occurs both with an externally applied magnetic field and without such field. The mechanism of intrusion is not yet explained.

We have obtained photographic evidence of fine scale structure near the polar region which is flute like, in two distinctly different types of dipole experiment, (both experiments, however, are made without external magnetic field).

The first type of experiment employs a set of 5 copper button guns with 100 joules of stored energy, producing 10^{14} /cc copper ions, moving at 2×10^6 cm/sec for 12 μ sec. The guns are 18 cm upstream from the dipole axis. The dipole coil is 5 cm in diameter, with a peak magnetic moment of 1.6×10^5 gauss-cm³, and a quarter period of 400 μ sec. The background pressure was 5×10^{-5} mm Hg.

Fig. 1 shows an Abtronics Image Converter photograph looking down on the dipole, taken after the gun fires with a 1 μ sec exposure at maximum brightness. The magnetospheric boundary is broken into flute-like streamers. The streamers may be observed (in successive shots) from the earliest photograph at 4 μ sec to one at 14 μ sec in which detail is lost through dimming of the image. Neither the position nor the number of the streamers is constant from shot to shot. This multiple-streamer structure is not visible when viewed along the equatorial plane because of the geometry.

Fig. 2 shows an idealization of a three dimensional structure which could give the effect seen in Fig. 1. Fig. 1 also gives some evidence of the same type of streamers existing inside the magnetosphere as well as on the boundary.

The second type of experiment is not strictly a solar wind, but is more like a "Starfish" explosion since the button gun is fired in close to the dipole, so that the plasma stream is smaller than any possible magnetospheric boundary. Here a single copper button gun with 5 joules of stored energy is put 8 cm upstream of the dipole axis in the equatorial plane. The dipole coil is 2.5 cm in diameter with a peak magnetic moment of 3.8×10^4 gauss-cm³ and a quarter period of 350 μ sec. The background pressure was 3×10^{-5} mm Hg.

Fig. 3 shows a time integrated photograph looking down on the South Pole of the coil. The streamers may be seen, and appear to be affected by the westward $E \times B$ drifts.

The streamers photographed in figures 1 and 3 are recognized by the

authors as plasma vortices or eddies, which have been observed already in several experiments where plasma proceeds across a magnetic field.^{1,8,9}

Plasma eddies appear to be generated in situations where there is initially shear in plasma velocity across the magnetic field. Generally the eddies are observed to rotate as rigid bodies (i.e. with constant ω) and have a density distribution which is peaked at the center of the eddy and goes to essentially zero at the periphery. The eddies generally line up with the magnetic field and in the case of figures 1 and 3 they line up with the dipole field lines.

In the case of the experiment represented by figures 1 and 3, probe measurements of electric field perpendicular to B have strongly indicated the presence of such eddies.

Plasma eddies in other experiments¹⁰ have been observed to have been created in a fraction of a microsecond and to endure for scores of microseconds. The plasma eddies of figures 1 and 3 are very likely the outgrowth of Rayleigh-Taylor instability flutes which occur when the plasma is decelerated by the magnetic field of the dipole. Any shear in velocity in the growth of the flute can be expected to produce vortices.

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Figure Captions

Fig. 1 - Image converter photograph (1 μ sec exposure time) of the polar view of plasma flow over a 5-cm-diam. ring dipole. The battery of 5 copper button guns is 18 cm to the left of the coil. Time 6 μ sec after start of gun firing.

Fig. 2 - Sketch of a possible structure which would provide the effect seen in Fig. 1.

Fig. 3 - Time exposure photograph of the polar view of a single copper button gun firing along the equatorial plane into the magnetic field of a 2.5-cm-diam. ring dipole.

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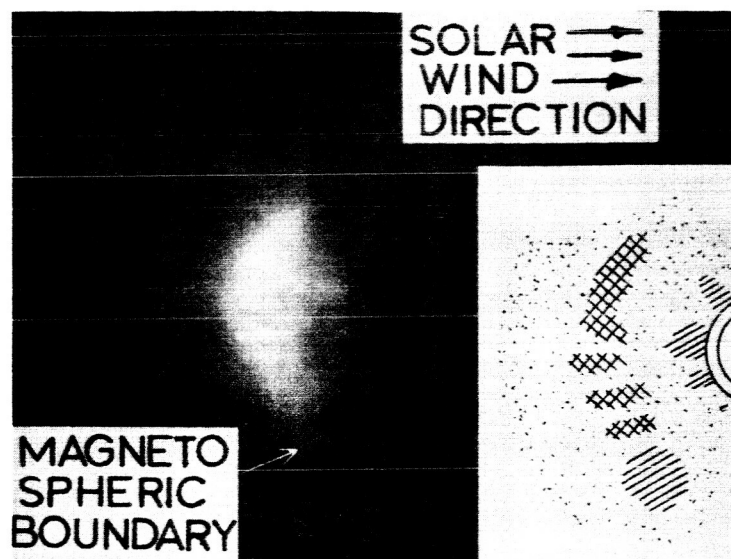


FIG. 1

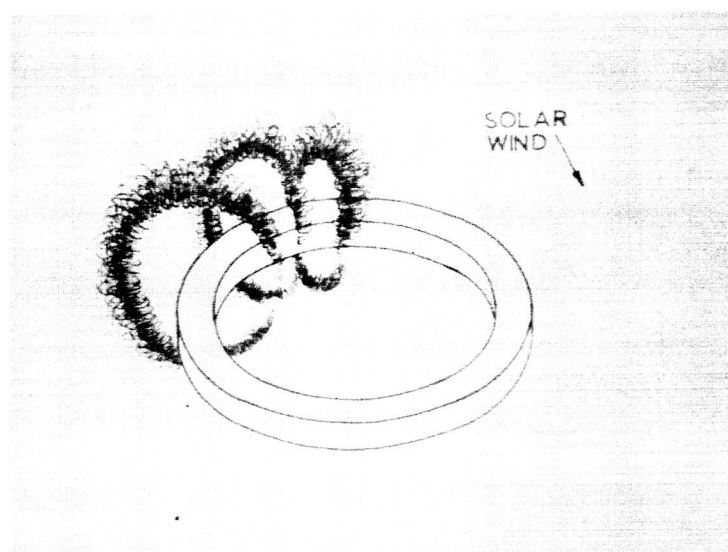


FIG. 2

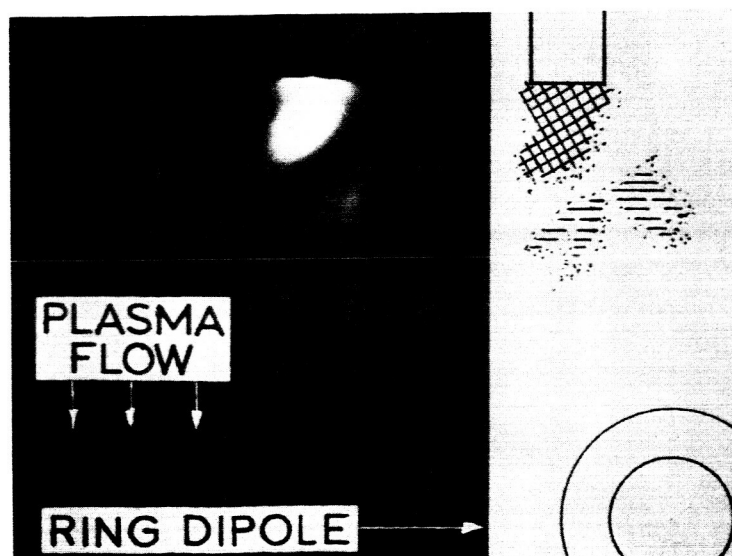


FIG. 3